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HIGH-BULK MODULUS CELLULAR RUBBER FOR WEAPON APPLICATIONS

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TECHNICAL REPORT

RESEARCH DIRECTORATE

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Rubber compounds based on Neoprene, oil extended EPDM and a fluorosilicone/silicone blend were developed for use in the molding of cellular materials that have a limited amount of cell structure. The high-bulk modulus cellular materials had lower tensile strength, elongation, hardness, and modulus than the solid controls, as was expected. Several of the EPDM-based cellular materials had reasonably high strength. The age resistance of the materials was as good or better than the controls when based on compression deflection results. The

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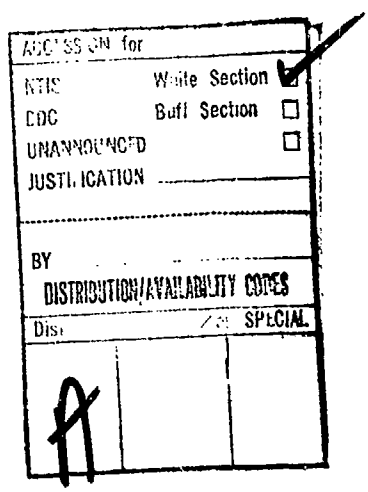
Compression and bulk moduli of the cellular materials were lower than the solid controls, but were considerably higher than commercial grades of cellular rubber. Several cellular materials that have been developed should perform better in such applications as gaskets, springs, and buffers than commercially available cellular materials.

CONTENTS



OBJECTIVE:

The objective of this work was to develop cellular rubber compounds having higher degrees of firmness (high-bulk moduli), and better strength and age resistance than those of currently available cellular materials.

BACKGROUND:

In the current Army Weapon systems, the volume compressibility of cellular rubber is taken advantage of by the use of cellular materials for isolation of shock and vibration, for seals and gaskets, and for cushioning material for packaging. The usefulness of such items could be greatly enhanced if their strength, abrasion resistance, resistance to aging, and ability to resist stiffening and embrittlement at low temperature could be improved to the extent that little difference would occur in the properties of a solid rubber product and its cellular counterpart.

Solid rubber, regardless of its degree of stiffness, has very low-volume compressibility and cannot be used successfully as an energy-absorbing device unless space is provided for lateral expansion of the rubber. Cellular rubber, however, by virtue of its gas-filled cells can be compressed while it is laterally confined and can thus absorb energy in situations where solid rubber would be ineffective.

APPROACH:

In the development of a high-bulk modulus cellular rubber, a method for conveniently determining the bulk modulus of prepared materials was deemed necessary. A method developed by Warfield[1] based on compression loading in a modified Matsuoka-Maxwell[2] type apparatus was selected. This method describes a technique for rapidly determining Young's modulus (E) and bulk modulus (B) on solid polymers and is suitable for measuring the moduli of materials having Poisson's ratios (u) in the range of 0.35 to 0.49. In general, most polymers fall within this range and, the belief was that high bulk modulus cellular rubber would be included.

1. Robert W. Warfield, Naval Ordnance Laboratory Technical Report 68-212, Feb. 1969.

2. S. Matsuoka and B. Maxwell, J. Polym. Sci. 32 131 (1958)

The method involves the use of an undersized specimen in a standard bulk compressibility tester. Using this method it is possible to determine moduli (E and B) on the same specimen in a single test. Initial loading of the undersized specimen results in a decrease in length and an increase in diameter. From these changes and the force required to produce them, Young's modulus may be calculated.

After the bore of the tester is filled by the deflection of rubber, the application of additional force results in a decrease in the volume of the specimen from which bulk modulus may be calculated. Both determinations may be made within minutes.

For solids that follow Hooke's law, Young's modulus (E) is defined as the ratio of tensile stress to tensile strain, and is usually determined in tension. Thus, Young's modulus may be determined in compression, as compression modulus, and the same general modulus equation holds:

$$\text{Compression modulus} = \frac{\text{Compressive stress}}{\text{Compressive strain}} = \frac{\text{force per unit area}}{\text{decrease in length per unit length}} = \frac{F/A}{l/l_o} \quad (1)$$

where (F) is compressive force, (A) is the cross-sectional area. (l_o) is the original length, and (l) is the change in length due to (F).

The second modulus of interest is the bulk modulus (B) which is defined as the ratio of hydrostatic pressure (P) to the volume strain, as follows:

$$B \quad \frac{\text{Hydrostatic pressure}}{\text{Volume change per unit volume}} = \frac{P}{V/V_o} = \frac{PV_o}{V} \quad (2)$$

where (P) is the compressive force, (V_o) is the original volume of the specimen and (V) is the change in volume caused by (P).

After "E" and "B" are obtained, Poisson's ratio (μ) can be calculated by use of the relationship involving μ, E, and B in the following form:

$$\mu = 1/2 - \frac{E}{6B} \quad (3)$$

shear modulus (N) may also be calculated as follows:

$$N = \frac{E}{2(1+\mu)} \quad (4)$$

A bulk compression test cell of the piston displacement type was

constructed. This cell consists of an outer steel casing fitted with steel plungers, as shown in Figure 1. In preparation for an experimental determination, the specimen is inserted into the bore of the casing, and the two steel plungers are then inserted into the open ends of the casing bore. The entire assembly is then placed between the plates of a compression cage that has been mounted within the environmental chambers of an Instron Universal Test Machine. The specimen is loaded in compression by downward pressure on the plungers by the plates of the compression cage. The load and plunger travel are automatically recorded to give a stress-strain chart. Measurements are made at 72 F., -40°F. and +158°F.

In the stress-strain plot for a typical cellular rubber (Figure 2), two changes in slope will be noted. Young's modulus or compression modulus was calculated as follows:

A tangent (T_1) was drawn to the initial change in slope. A normal, (N_1), was dropped from a point on T_1 to the y axis, the distance between the points at which N_1 and T_1 intersect the y axis being the measure of the specimen deformation Δl_1 for a force F_1 equal to the distance N_1. In this portion of the cycle the specimen is expanding and deforming to fill the bore of the tester.

Young's modulus or compression modulus is calculated with the use of the equivalent of equation (1):

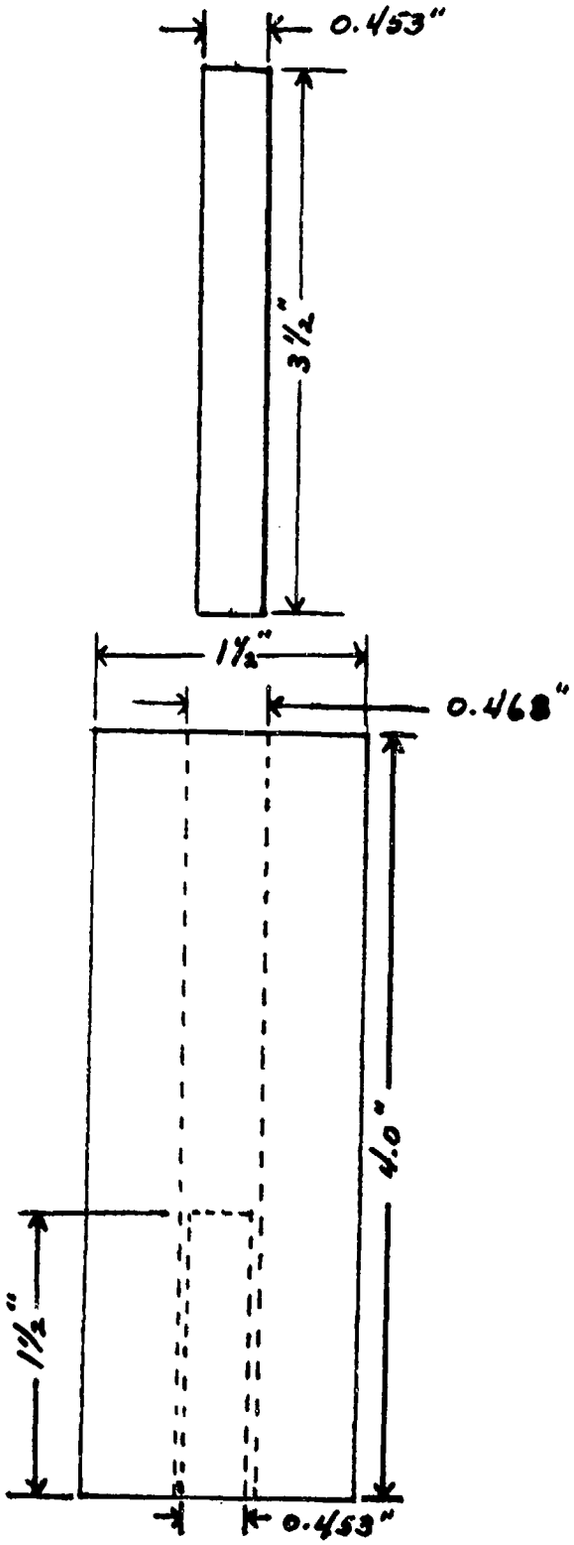
$$E = \frac{F_1 \times l_o}{A \times \Delta l_1} \qquad (5)$$

where l_o is original specimen length and A is the area of the plunger which transmitted the load.

The third stage of the stress-strain plot is developed when the specimen can no longer expand radially in an unrestricted manner because the deformed specimen has completely filled the bore of the test fixture and bulk compression has taken place. The slope of stage three is the bulk modulus of the specimen. To obtain the bulk modulus (B), a tangent T_2 is drawn and a normal N_2 is dropped to the ordinate to determine Δl_2, the change in length while under compression. The following relationship which is equivalent to equation (2) is used to calculate (B):

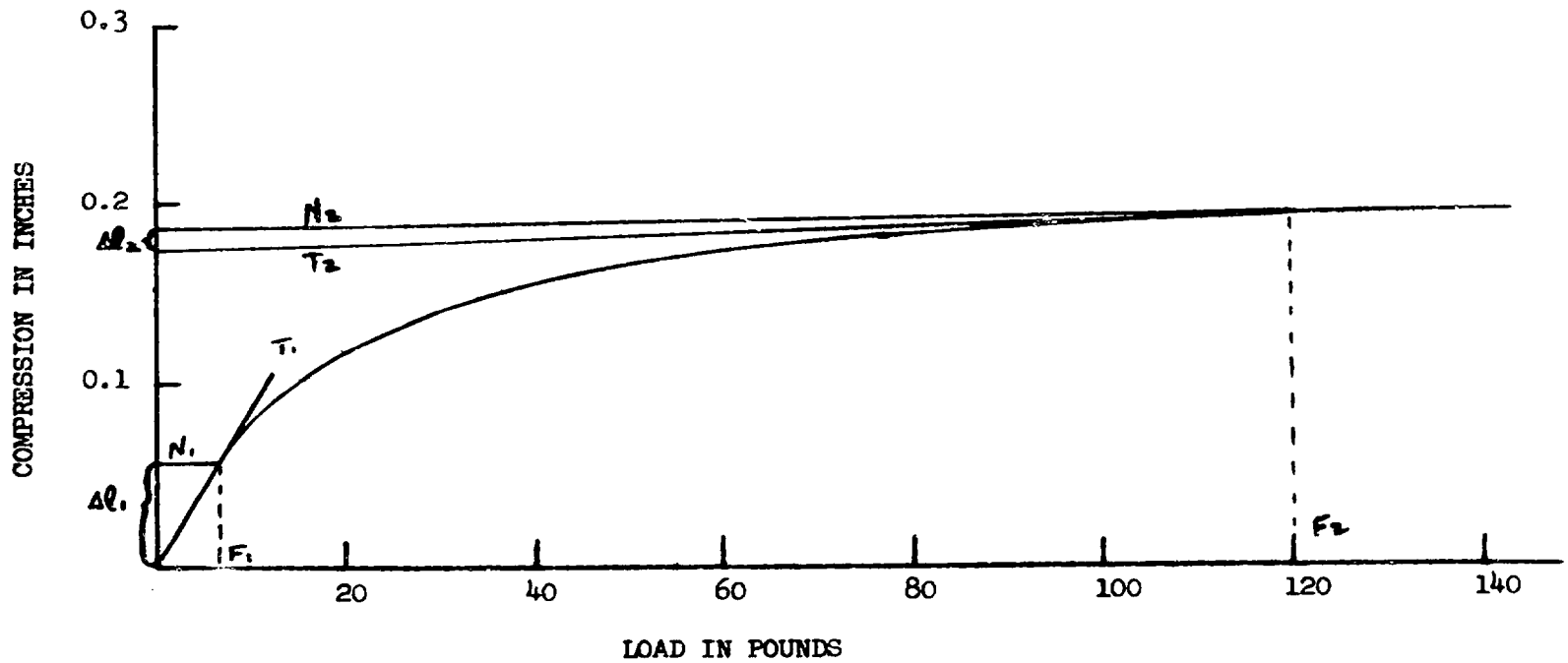
$$B = \frac{F_2 \times l_o}{A \times \Delta l_2} \qquad (6)$$

where F_2 is the force required to produce the change in specimen length.



BULK COMPRESSION CELL

Figure 1



STRESS-STRAIN CURVE FOR CELLULAR RUBBER

Figure 2

The second stage may be disregarded since the belief is that this stage develops when barrel deformation, typical of rubber in compression, reaches a point at which lateral deformation and some bulk compression are occurring simultaneously. The second stage represents the period during deflection when the center portion of the barrel-shaped specimen reaches the compression cell wall and the time when deflection of the entire specimen ceases because of the compression cell wall.

The high bulk modulus cellular materials developed during this study were based on Neoprene WD, Neoprene WRT, an oil-extended ethylene propylene diamine terpolymer (EPDM), and a fluorosilicone-silicone blend. Formulations for these compounds are given in Table 1.

Two commonly used methods of producing cellular rubber are available, namely, free-blown and press-blown.[3] As the name implies, free-blown cellular rubber is made with rubber unconfined during blowing. The extrusions, calendered sheets, or other preformed blanks are blown and vulcanized in an autoclave or oven. In the preparation of press-blown cellular rubber, the entire process is conducted in the vulcanizing press. Press-blown cellular rubber is used for making parts to close dimensional tolerance and parts of higher density than can be produced by free-blowing. Two methods of press-blowing are available, a one-step and a two step method.[3] Both methods start with a preform of rubber confined in a mold form, frame or chase in a hot press. With the one-step method, a preform is blown to finish size and is completely vulcanized in the press under pressure. The two-step method involves the hot-pressing of preform just long enough to partially vulcanize it, then the free-blowing of it in a hot-air circulating oven or a hot press equipped with shims to maintain the desired thickness. In the fabrication of cellular pads, a 4 by 4 by 1/2 inch (102 by 102 by 12.7 millimeter) frame was used. The preform was placed in the frame between 1/8 inch thick hardboard liners covered with nylon cloth which had been dusted with talc. This procedure provided a uniform skin and prevented the trapping of gas on the surface; thus, the formation of surface blisters was prevented. The degree of cell structure and the density for the one-step method were controlled by the amount of rubber placed in the mold. Close control of time, temperature, and mold-loading is essential to maintain uniformity of finished product. The degree of cell structure and the density of the finished product for the two-step method were controlled by time of precure.

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3 Fabricating with Silastic Brand Rubber, Dow Corning Manual, 1968, p 41-43

TABLE 1

COMPOUND FORMULATIONS FOR CELLULAR RUBBER

INGREDIENT	PARTS BY WEIGHT								
	C31	C35	C35-1	C36	C38	C42	C44	C45	C46
Neoprene WRT				100					
Neoprene WD	100	100	100		100				
EPDM (Oil Extended)						200	200	200	
Fluorovinyl Silicone									50
Phenylvinyl silicone									50
Magnesium oxide	4	4	4	4	4				
Zinc oxide	5	5	5	5	5	5	5	5	
Ferric oxide									3
Neozone A		1	1						
Akroflex CD				3	3				
MT Black N990		5	5			100	100	100	
SAF Black N110	40			60	55				
FEF Black N550						50	50	50	
Whiting		95	95						
Talc						50	50	50	
Microcell E									3
Process oil		15	15						
DOS	20			35	35		25	25	
Petrolatum	3	3	3	3	3				
Urea		1.1	1.1	1.1	1.1	1	1	1	
Unicell ND	0.25	3		3	3	2.5	2.5		3
Nitrosan			2					5	1.5
NA - 22	0.50	1	1	1	1				
Sulfur						1.5	1.5	1.5	
Tuads						1.5	1.5	1.5	
Captax						0.5	0.5	0.5	
Cadox TS-50									1
Lupersol 101									1.5

Stress-strain specimens were sliced from the edges of the 4 by 4 by 1/2 inch (102 by 102 by 12.7 millimeter) cellular pads. Compression specimens 0.45 inch (11.4 millimeter) in diameter were cut from the 0.5 inch (12.7 millimeter) blown and cured pads by means of a rotary cork borer, with the use of a No. 6 die lubricated with soap solution. A slow-feed rate was used to keep the specimen sidewalls as straight as possible.

Compression and bulk modulus determinations were conducted on materials developed and on two commercial cellular materials with the use of the compression cell previously described. The effect of elevated and reduced temperatures on modulus was determined with a compression cage and the bulk compression cell inclosed in a Meismer Environmental chamber mounted between the crossheads of an Instron Test Machine. Compression tests were conducted at temperatures of -40°F. (233.2°K), 72°F. (295.4°K), and 158°F. (343.2°K). All testing except the determination of compression and bulk moduli was conducted in accordance with ASTM procedures.

RESULTS AND DISCUSSION:

Cellular Neoprene compounds C31, C35, C35-1, and C36 were prepared by both the one- and two-step methods. The one-step method produced a more uniform product with evenly dispersed cell structure. The two-step process exhibited a tendency to produce surface blisters and uneven cell structure. Finished dimensions were difficult to control, and pads exhibited a tendency to warp during oven-curing. Results of tests conducted on these compounds are given in Table 2.

Compound C31 had insufficient blowing agent in it, and the product was nearly a solid rubber. Compounds C35 and C35-1 were patterned after a commercial sponge formulation, which contained high loadings of mineral filler. The properties of these compounds were controlled by proper loading and were considered good for cellular material. Their poorest feature was their low bulk modulus at 158°F. compared with the modulus at room temperature.

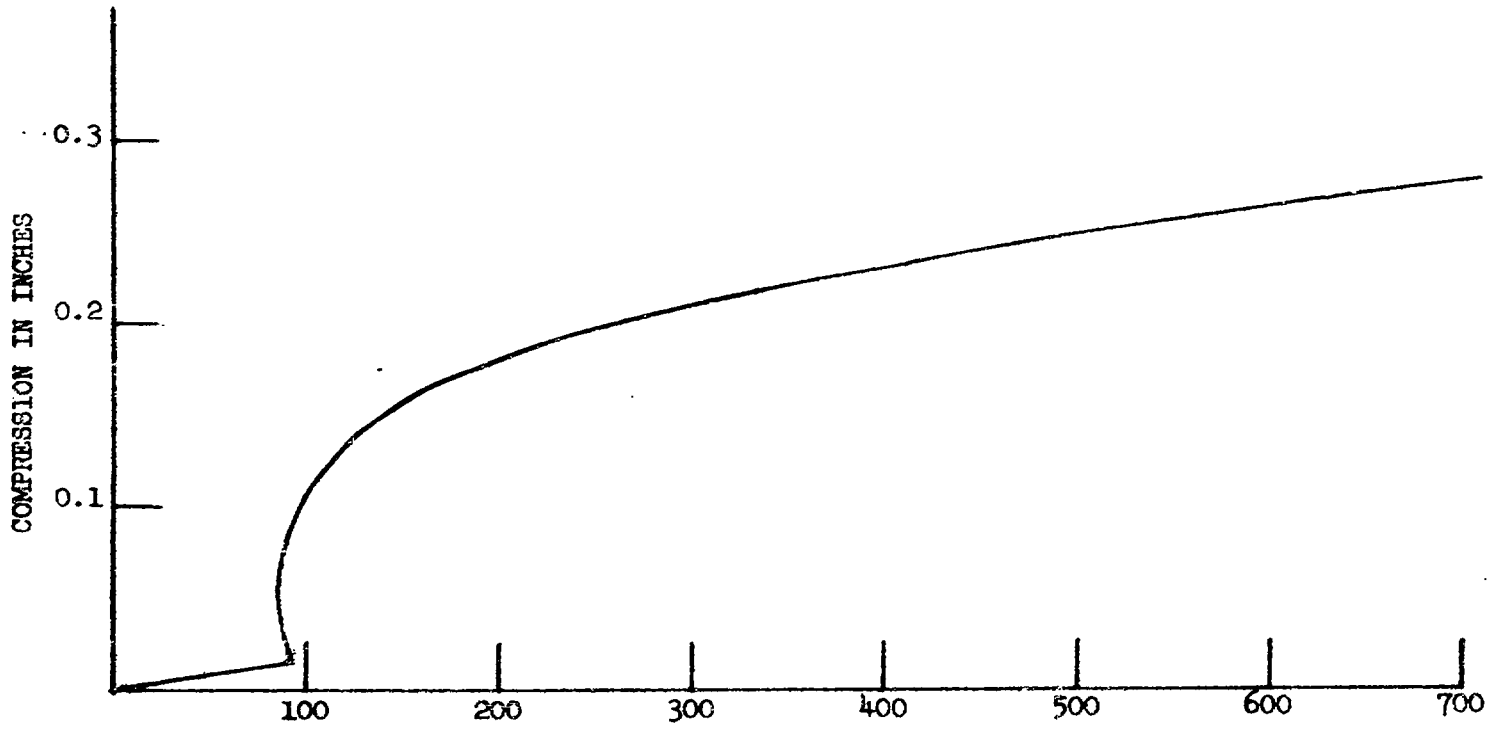
Almost all physical properties of cellular compound C36 (#2) compared favorably to the properties of the solid control. However, at -40°F, the material became so stiff that considerable force was required to initiate deflection during the compression test. The load-deflection curve for this material is shown in Figure 3. Very little deflection was realized on loading until a point was reached at which deflection increased rapidly with only a small increase in force. This resulted in a very high modulus of compression.

Neoprene-based compound C38 as well as those based on EPDM and the fluorosilicone/silicone blend, with one exception, were prepared by the

TABLE 2

PHYSICAL PROPERTIES OF HIGH-BULK MODULUS NEOPRENE COMPOUNDS

	C31	C35 #1	C35 #2	C35 #3	C35-1 #1	C35-1 #2	C35-1 #3	C36 Solid Control	C36 #2	C38 Solid Control	C38 #2	C38 #3	C38 #4	C38 #5	C38 #6	C38 #7
Tensile strength, MPa	-	1.2	2.6	4.3	2.4	4.1	2.8	12.5	4.1	13.9	6.2	4.1	4.7	2.9	3.9	5.6
psi	1300	180	370	620	340	600	400	1810	600	2020	900	590	680	400	560	810
Modulus @ 100% E, MPa	-	0.8	1	1.1	1	1.2	0.8	2.2	1.6	1.9	0.6	0.8	0.9	0.6	0.6	0.7
psi	-	110	150	160	150	170	110	315	230	270	90	110	130	80	80	100
Modulus @ 200% E, MPa	-	-	2.3	1.8	1.7	2.1	1.1	8.4	-	7.1	3.9	4.4	3.1	1.9	2.4	3.6
psi	-	-	330	260	240	310	160	1213	-	1030	560	630	450	280	350	520
Modulus @ 300% E, MPa	-	-	-	2.3	2.3	3	1.5	-	-	10.5	-	-	-	-	-	-
psi	1110	-	-	330	330	430	210	-	-	1520	-	-	-	-	-	-
Elongation, %	320	190	245	590	365	485	545	245	160	310	245	205	250	235	250	225
Hardness, Shore A	50	28	42	46	47	49	38	62	50	65	49	50	40	35	39	49
Tear Die C, kN/m	-	-	-	13.5	-	-	14.7	-	-	-	-	-	-	-	-	-
lb/in	206	-	-	77	-	-	84	-	-	-	-	-	-	-	-	-
Compression set, %	-	7	6	-	10	12	-	6	9	7	8	9	10	-	-	-
Density, kg/m^3	1216	497	513	929	577	849	1025	1330	1089	1250	1218	961	785	657	721	897
lb/ft^3	76	31	32	58	36	53	64	83	68	78	76	60	49	41	45	56
Compression deflection @ 25% compression, kPa	-	41	48	248	90	165	193	1330	599	1385	1357	657	269	214	255	675
psi	-	6	7	36	13	24	28	193	87	201	197	98	39	31	37	98
Resilience, % rebound	-	16	25	44	33	42	46	38	41	38	43	44	41	42	45	43
70 hr @ 212°F. (373.2°K) in air:																
Compression deflection @ 25% compression, kPa	-	90	351	296	324	345	296	1592	661	1495	1406	751	661	579	613	744
psi	-	13	51	43	47	50	43	231	96	217	204	109	96	84	89	108
Hardness, Shore A	-	32	49	49	50	53	49	64	50	69	53	51	43	45	47	51
Compression modulus:																
@ -40°F. (233.2°K), MPa	-	-	-	5.7	-	-	16.5	-	75.8	13.1	-	4.6	2.3	-	-	5.2
psi	-	-	-	8.3×10^2	-	-	2.4×10^3	-	1.1×10^4	1.9×10^3	-	6.7×10^2	3.4×10^2	-	-	7.5×10^2
@ +72°F. (295.4°K), MPa	4.8	-	-		-	-	1.1	7.6	2.6	5.9	-	2.1	0.9	-	-	2.1
psi	7×10^2	-	-	1.5×10^2	-	-	1.6×10^2	1.1×10^3	3.8×10^2	8.5×10^2	-	3×10^2	1.3×10^2	-	-	3.1×10^2
@ +158°F. (343.2°K), MPa	-	-	-	1.1	-	-	0.8	-	0.9	4.7	-	1.7	0.8	-	-	2.1
psi	-	-	-	1.6×10^2	-	-	1.1×10^2	-	1.3×10^2	6.8×10^2	-	2.5×10^2	1.2×10^2	-	-	3×10^2
Bulk Modulus:																
@ -40°F. (233.2°K), MPa	-	-	-	613.2	-	-	358.3	-	220.5	1309.1	-	661.4	633.9	-	-	289.4
psi	-	-	-	8.9×10^4	-	-	5.2×10^4	-	3.2×10^4	1.9×10^5	-	9.6×10^4	9.2×10^4	-	-	4.2×10^4
@ +72°F. (295.4°K), MPa	53.1	-	-	461.6	-	-	420.3	965	215.6	530.5	-	434.1	330.7	-	-	434.1
psi	7.7×10^3	-	-	6.7×10^4	-	-	6.1×10^4	1.4×10^5	3.1×10^4	7.7×10^4	-	6.3×10^4	4.8×10^4	-	-	6.3×10^4
@ +158°F. (343.2°K), MPa	-	-	-	22	-	-	24.8	-	22	330.7	-	110.2	130.9	-	-	82.7
psi	-	-	-	3.2×10^3	-	-	3.6×10^3	-	3.2×10^3	4.8×10^4	-	1.6×10^4	1.9×10^4	-	-	1.2×10^4
Poisson's Ratio	0.485	-	-	0.499	-	-	0.499	0.499	0.489	0.498	-	0.499	0.499	-	-	0.499
Precure @ 307°F. (425.9°K), min.		6	7		7	10			10							
Postcure @ 307°F. (425.9°K), min.		24	23		23	20			20							
Preform @ 307°F. (425.9°K), sec.																
Cure @ 307°F. (425.9°K), min.				30			30	30		30	30	30	30	30	30	30
Mold loading, gms.										Excess Rubber	132	132	107	132	132	132
Pressure on mold, MPa										6.9	6.9	6.9	1.4	1.4	1.4	3.4
psi										1000	1000	1000	200	200	200	500



COMPRESSION CURVE FOR CELLULAR RUBBER AT -40° F.

Figure 3

one-step method. The exception was compound C42, No. 7, which was prepared by the two-step procedure. Again, this method produced a poorer material compared with the product obtained with the one-step method. The properties of the six-cellular Neoprene compounds, C38 series, produced by the one-step method are compared with the properties of the solid parent-compound in Table 2. The bulk moduli of the cellular compounds are high since they are just slightly lower than the control. The closed-cell construction was very fine, and the cells were evenly dispersed. Compared with the control, these cellular materials have lower tensile strength, elongation, hardness, and modulus as expected; however, the tensile strength of Nos. 2 and 7 are quite good. Resilience was about the same for the solid control and for all six cellular materials. Age resistance of materials Nos. 2, 3, and 7 was excellent. These compounds were molded at high pressure and have high-bulk moduli; thus, they more nearly resemble solid rubber with its good age-resistance. The cellular materials did not increase in bulk modulus at -40° F. (233.2° K) to the same degree as was the case with the solid rubber control, which is a point in favor of the cellular material.

Compounds in the C42 series, based on EPDM, were prepared by both the one-step and two-step methods. These cellular materials are compared with the solid parent-compound in Table 3. Again, the softest material was produced by the two-step method. The cellular materials Nos. 9 and 10, when they were compared with the control, have shown good tensile strength, elongation, hardness, and modulus for a cellular material. The resilience was essentially the same for the control and for the three cellular materials. The bulk moduli for the cellular materials were considerably lower than those of the control, but were less affected by changes in temperature. A low-temperature plasticizer was added to the EPDM compound C44, but the improvement in low-temperature behavior was marginal. Compound C45 was the same as C44, except that different blowing agents were used. No significant differences in properties resulted but the cell structure in C45 was finer and more evenly dispersed.

One solid and four cellular materials, based on a fluorosilicone/silicone blend, were developed and evaluated. Their properties are presented in Table 4. The strength of the cellular rubber was considerably lower than the parent solid-rubber. The bulk moduli of cellular materials Nos. 3 and 4 at room temperature are higher than those of Nos. 2 and 5, and more nearly resemble the parent rubber. An increase in temperature has more effect on the cellular material than a decrease in temperature.

Two commercially prepared cellular rubbers, one a SCE7 grade, (MIL-STD-670) and the other a specially prepared shock-absorbing foam, Ensolite AK, were included for comparison with the high bulk modulus cellular rubbers.

TABLE 3
PHYSICAL PROPERTIES OF HIGH-BULK MODULUS EPDM COMPOUNDS

Property Measured	Solid Control	C42 #7	C42 #9	C42 #10	C44 #1	C45 #1
Tensile strength, MPa	7.3	3.7	5.3	5.9	5.9	6
psi	1060	530	770	850	850	870
Modulus @ 100% E, MPa	1.1	-	-	-	-	-
psi	160	-	-	-	-	-
Modulus @ 200% E, MPa	2.5	-	-	-	-	-
psi	370	-	-	-	-	-
Modulus @ 300% E, MPa	3.9	1.7	2.5	2.4	2.6	2.5
psi	570	240	360	340	380	360
Elongation, %	620	465	625	670	605	655
Hardness, Shore A	45	32	37	39	36	37
Tear, Die C, kN/m	-	29.8	27.1	28.7	23.5	29.8
lb/in	-	170	155	164	134	170
Compression set, %	10	28	15	16	11	13
Density, kg/m^3	1233	657	961	1105	961	1009
lb/ft^3	77	41	60	69	60	63
Compression Deflection @ 25% compression, kPa	689	110	372	390	384	352
psi	100	16	54	58	56	51
Resilience, % Rebound	49	57	50	53	52	52
70 Hr. @ 212°F. (373.2°K) in air:						
Compression deflection, @ 25% compression, kPa	1082	152	524	656	524	524
psi	157	22	76	95	76	76
Hardness, Shore A	52	38	43	46	44	43

TABLE 3 (Continued)
PHYSICAL PROPERTIES OF HIGH-BULK MODULUS EPDM COMPOUNDS

	Solid Control	C42 #7	C42 #9	C42 #10	C44 #1	C45 #1
Compression Modulus:						
@ -40°F. (233.2°K), MPa	12.7	1.5	3.9	3.8	2.7	2.6
psi	1.8×10^3	2.2×10^2	5.7×10^2	5.5×10^2	3.9×10^2	3.8×10^2
@ +72°F. (295.4°K), MPa	6.1	1.2	1.4	1.5	1	1.2
psi	8.8×10^2	1.7×10^2	2×10^2	2.2×10^2	1.6×10^2	1.8×10^2
@ +158°F. (343.2°K), MPa	2.3	0.8	0.7	0.6	1	1
psi	3.4×10^2	1.2×10^2	1×10^2	0.9×10^2	1.4×10^2	1.4×10^2
Bulk Modulus:						
@ -40°F. (233.2°K), MPa	1102.4	280.4	261.8	427.2	296.3	344.5
psi	1.6×10^5	4.1×10^4	3.8×10^4	6.2×10^4	4.3×10^4	5×10^4
@ +72°F. (295.4°K), MPa	895.7	165.4	234.3	318.3	227.4	303.2
psi	1.3×10^5	2.4×10^4	3.4×10^4	4.6×10^4	3.3×10^4	4.4×10^4
@ 158°F. (343.2°K), MPa	329.3	82.7	206.7	315.6	234.3	310.1
psi	4.8×10^4	1.2×10^4	3.0×10^4	4.6×10^4	3.4×10^4	4.5×10^4
Poisson's Ratio.	0.498	0.499	0.499	0.499	0.499	0.499
Precure @ 307°F. (425.9°K), min.		10				
Postcure @ 307°F. (425.9°K), min.		35				
Cure @ 307°F. (425.9°K), min.	45		45	45	30	30

TABLE 4

PHYSICAL PROPERTIES OF HIGH-BULK MODULUS CELLULAR FLUOROSILICONE/SILICONE BLEND COMPOUNDS

Property Measured	Solid Control	C46 #2	C46 #3	C46 #4	C46 #5	Commercial Cellular Material Grade SCE 7	Commercial Cellular Material Ensolite AH
Tensile strength, MPa	9.1	1.2	1.6	1.1	1.9		
psi	1320	170	230	230	270		
Modulus @ 100% E, MPa	3	0.7	1	1	1		
psi	310	100	150	150	150		
Modulus @ 200% E, MPa	7.8	-	-	-	-		
psi	810	-	-	-	-		
Elongation, %	300	150	150	115	160		
Hardness, Shore A	61	30	46	37	45		
Tear, Die C kN/m	-	4.9	3.6	-	4.9		
lb/in.	-	28	21	-	28		
Compression set, %	-	7	24	20	26		
Density, kg/m^3	-	721	1185	881	977	240	112
lb/ft^3	-	45	74	55	61	15	7
Compression deflection @ 25% compression, kPa	1516	186	766	676	621		
psi	220	27	111	98	90		
Resilience, rebound %	27	31	28	32	33		
70 hrs @ 212°F. (373.2°K) in Air:							
Compression deflection @ 25% compression, kPa	-	179	649	283	311		
psi	-	26	94	41	45		
Hardness, Shore A	-	34	49	42	45		

TABLE 4 (Continued)

PHYSICAL PROPERTIES OF HIGH-BULK MODULUS CELLULAR FLUOROSILICONE/SILICONE BLEND COMPOUNDS

	Solid Control	C46 #2	C46 #3	C46 #4	C46 #5	Grade SCE 7	Ensolite AH
Compression Modulus							
@ -40° F. (233.2° K), MPa		0.9	4.8	3.0	2.1		
psi		1.3×10^2	6.9×10^2	4.3×10^2	3.1×10^2		
@ +72° F. (295.4° K), MPa	3.6	1.3	3.7	2.8	2.1	0.2	1.8
psi	5.2×10^2	1.9×10^2	5.4×10^2	4×10^2	3.1×10^2	34	2.6×10^2
@ +158° F. (343.2° K), MPa		0.5	2	1.6	1.7		
psi		0.7×10^2	2.9×10^2	2.3×10^2	2.4×10^2		
Bulk Modulus							
@ -40° F. (233.2° K), MPa		361.3	503	551.2	337.6		
psi		5.4×10^4	7.3×10^4	8×10^4	4.9×10^4		
@ +72° F. (295.4° K), MPa	715.8	351.4	461.6	461.6	296.3	6.1	61.3
psi	1.04×10^5	5.1×10^4	6.7×10^4	6.7×10^4	4.3×10^4	8.8×10^2	8.9×10^3
@ +158° F. (343.2° K), MPa		149.5	268.7	268.7	296.3		
psi		2.2×10^4	3.9×10^4	3.9×10^4	4.3×10^4		
Poisson's Ratio		0.499	0.499	0.499	0.498	0.494	0.495
Preform @ 307° F. (425.9° K), sec.		45	45	60	60		
Cure @ 307° F. (425.9° K), min.	30	30	45	45	45		
Post Cure @ 300° F. (422° K), hr.	3	3	3	3	3		
@ 350° F. (449.8° K), hr.	4	4	4	4	4		
@ 400° F. (477.6° K), hr.	16	16	16	16	16		
Size of preform, in.		4x4x1/8	4x4x3/8	4x4x3/8	4x4x3/8		
Pressure on mold, MPa	3.4	3.4	3.4	3.4	3.4		
psi	500	500	500	500	500		

CONCLUSIONS:

Satisfactory procedures have been developed for molding cellular rubber compounds, which have a very limited amount of cell structure, from Neoprene, EPDM, and a fluorosilicone/silicone blend. Both the one-step and the two-step methods of producing cellular rubbers were used; however, the one-step method was much easier to control and produced more uniform cell structures.

The high bulk modulus cellular rubbers based on Neoprene and the fluorosilicone/silicone blend have rather low tensile strengths, but the EPDM-based cellular rubbers exhibited good strength when they were compared with solid-EPDM vulcanizates.

RECOMMENDATIONS:

Several of the cellular rubbers developed during this study should be investigated for their potential as reasonably high-strength, energy-absorbing materials. Applications where they should be suitable include all-rubber extractor springs for rifles and machine guns, and gaskets for the cupolas of the M551 and other vehicles.

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Rubber compounds based on Neoprene, oil extended EPDM and a fluorosilicone/silicone blend were developed for use in the molding of cellular materials that have a limited amount of cell structure. The high-bulk modulus cellular materials had lower tensile strength, elongation, hardness, and modulus than the solid controls, as was expected. Several of the EPDM-based cellular materials had reasonably high strength. The age resistance of the materials was as good or better than the controls when based on compression deflection results.

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